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Design and Tests of a Simple, Inexpensive Optical Beacon for Use on Small Satellites

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A standard photography flash unit modified for automatic repetitive flashing and presetable pulse duration was tested for its utility as an aid for optically acquiring a target in low earth orbit. The relative visibility of the flash with respect to repetition rate and pulse duration was measured with two types of low-light-level TV camera systems over a range of effective distances. Optimal operating parameters for the flash were determined for its application as an optical beacon on the small satellites used in the Chemical Release Observation (CRO) experiments, part of the Infrared Backgrounds and Signatures Survey (IBSS) Space Shuttle mission.

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PREFACE

We thank D. Cirilo of Aerospace for her organization of and participation in the ICID field test. In addition, we thank O. Graham and W. Rowan of NASA JSC for their expertise and participation during the ICID field test and for keeping the team rolling. We thank W. Thorn of AFGL for transporting the IBSS ICID cameras to the test site and for the setup and operations during the test. G. Lamb of Riverside Research Institute also participated in the video recording and assessment during the tests. NASA Ames Research Center kindly provided the LJO system for the ISIT tests, and Steward Observatory and Kitt Peak National Observatory personnel were very understanding and supportive during the ICID tests. The flash trigger circuit was provided by Tom Edmonston of Defense Systems Incorporated, McLean, Virginia, and implemented and optimized at The Aerospace Corporation.

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I. INTRODUCTION

Several experiments over the last few years (the Christmas Comet, barium releases, etc.) have involved a satellite on orbit which ground-based and/or airborne observers needed to acquire and track with optical instruments. In certain instances, the geometry and time of day can combine with the altitude of the satellite to provide a sufficiently bright reflected-light signature for the successful acquisition and tracking of the satellite. However, in other instances the experiment occurs at night in a low earth orbit and the reflected light is too faint. An obvious solution to this problem is to add an optical beacon that can be seen by the observers' optical sensors. In general, an optical beacon for this application must have the minimum size, weight, and power requirements needed to accomplish the task. At The Aerospace Corporation, we have been experimenting with a standard off-the-shelf photography flash modified to allow a variable flash rate and flash duration which can be tailored to a particular application.

A modified Vivitar model 283 photography flash unit has been incorporated as part of the small satellites to be used for the Chemical Release Observation[1] (CRO) portion of the Infrared Backgrounds and Signatures Survey (IBSS) mission scheduled for a Shuttle launch in mid 1990. The contractor constructing the CRO satellites, Defense Systems Incorporated, McLean, Virginia, evaluated a number of aircraft beacons and other commercial strobes and concluded that the most efficient light per watt-gm-cm^3-$ could be had by modifying the Vivitar model 283. In this application, the flash will be acquired by the Shuttle crew with a Low Light Level Television (L^3TV) system in order to more accurately point other infrared (IR), visible, and ultraviolet (UV) sensors at the satellite before and during a chemical release.

We are also hopeful that this flash can be detected by L^3TV camera systems used as part of sensor packages on aircraft and at ground sites that will be observing the chemical releases. In this case the flash unit may not be as important an aid for acquiring and tracking the satellite, but it might allow the satellite to be located prior to the release in the fields of view of the sensors. This information could prove to be very useful in analyzing imagery data with respect to the dynamics of the release, as the center of the release could be accurately pinpointed independent of the cloud signature itself. This report describes the flash and tests that were conducted to assess its visibility in a remote sensing mode with two different types of L^3TV cameras.

II. FLASH SELECTION

While flashing lights are commonly used in terrestrial and aircraft applications, they are not typically found on satellites. Thus, fabrication from scratch or modification of a flasher built for another application was necessary for the CRO application. Four types of off-the-shelf flashers were investigated for modification for CRO use: emergency vehicle strobes, aircraft anticollision strobes, emergency locator strobes for campers and boaters, and photography flash units. It should be noted that the first three of these types are designed to catch the attention of an unaided human observer, while photography flash units are designed simply to produce visible light as efficiently as possible. An intense short pulse is desirable for the photography application because it minimizes the time that a camera shutter must remain open, but for a human observer, the apparent brightness of a flash diminishes as the pulse duration is shortened, even though the pulse energy remains constant.[2,3] For this reason, vehicle, aircraft, and emergency locator strobes are often designed to produce two short, low energy pulses spaced close enough in time to appear as a single flash instead of a single short, high energy pulse to achieve the same effective brightness. In the CRO application, only the apparent brightness of the strobe as it appears to an observer viewing it with an L^3TV camera and monitor combination is important. In this respect, the photography flash is preferable because it will supply as many detectable photons as possible to the camera in a time less than a single TV frame. It is difficult, however, to predict in advance how light pulses significantly shorter than a single TV frame will appear on an L^3TV system, which is one reason why these tests were performed.

Inspection of examples of all four types of off-the-shelf flashers confirmed that, due to component outgassing and lack of thermal sinking, none of the candidates would perform without modification. Even at modest light output energy and flash frequency, the aircraft and land vehicle models are quite large and heavy. Furthermore, they are all adapted to

12-V operation, whereas the satellite bus voltage, accommodating an electronics payload of digital electronics, was already established at 6 V. Space for the dc-to-dc converter these strobes would require and the added power necessary to make up for converter losses are both at a premium on the satellite. In contrast, the emergency locator strobes are designed to flash for hours or days while operating on the equivalent of only four standard AA dry cells. Thus, their light output per flash is quite low (10 to 50 mJ), making their visibility nil at the ranges required here.

Because portability is a key element in amateur photography equipment, this group of products is much more compact and generally requires only 6 V (e.g., four AA cells). Furthermore, recent industry trends to supply larger flash energies have achieved compact units with single flash energies above 1 J. The Vivitar 283 was selected because it was among the most powerful (using flash guide number as the metric) of the compact designs which mount to the camera hot shoe above the prism/viewfinder. Table 1 shows that, in fact, about 10 J/flash is easily achieved with this model.

Table 1. Photometric and Radiometric Calibration Measurements

Index (R5 kΩ)	Duration (msec)	Brightness (cd-sec) w/lens	Brightness (cd-sec) w/o lens	Radiant Energy (J) w/lens	Radiant Energy (J) w/o lens
50	0.5	590	550	4.1 ± 0.1	4.5 ± 0.1
100	1.1	1050	980	6.4 ± 0.1	8.2 ± 0.2
150	1.8	1330	1210	7.9 ± 0.1	10.0 ± 0.3
200	2.4	1490	1390	8.6 ± 0.2	11.1 ± 0.3
250	2.9	1590	1490	9.2 ± 0.2	11.6 ± 0.3
300	3.5	1610	1500	9.9 ± 0.1	12.0 ± 0.2
350	4.0	1700	1590	10.3 ± 0.1	13.2 ± 0.3
400	4.7	1810	1590	10.6 ± 0.1	13.5 ± 0.3

Modifications for flight were motivated by the need to make the unit flightworthy and by the demands of the detection system. The latter points are addressed below. The easiest way to protect commercial electronics for short term space application is potting in epoxy. This prevents electrolytic devices from exposure to space vacuum which may cause leakage and provides mechanical support against launch vibration loads. Potting also provides adequate thermal sinking of components which normally rely on conductive and convective cooling from the ambient atmosphere.

Before potting, the flash electronics were separated onto three discrete boards. This allowed packaging into the conformal housing (Fig. 1) which best accommodated the available mounting space on the satellite. The feedback circuit controlling flash energy was replaced with a potentiometer which was preset before potting. The flash power was adjusted to ensure the flash frequency requirement was met and to keep power draw within that budgeted for the unit. The first potted unit was used in the visibility tests described in this paper. All units were subjected to vibration testing and were run in a thermal vacuum chamber where they were continuously operated in vacuum at 1 flash/sec for 72 hr and cycled between +60°C and -60°C. Typical operation plans call for approximately 10 min of operation on orbit. No failures in the flight units have occurred in this type of testing to date. One unit failed during the camera tests, as described below, but appears to have been caused by a flash tube lifetime problem rather than a failure due to the environment.

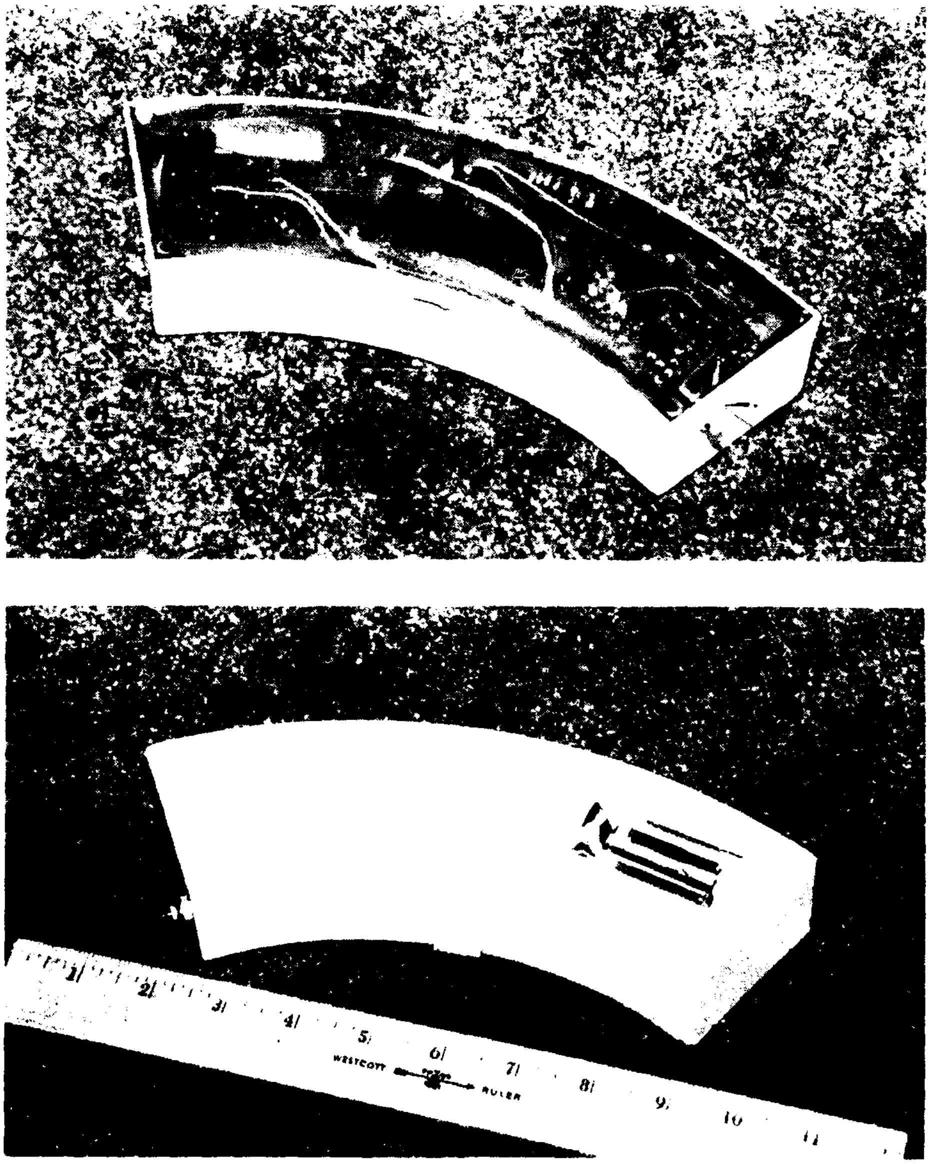

Fig. 1. The Vivitar model 283 photography flash unit as modified for the CRO satellite. (a) Rear view of the unit revealing the electrostatic components potted in epoxy. (b) Front view showing the flash tube and reflector. The unit weighs about 1.6 lb.

III. FLASH DESCRIPTION

The flash trigger and quench of the Vivitar model 283 pictured in Fig. 1 are controlled with the external timing circuitry shown in Fig. 2. Components R2 and C1 control the frequency of one half of the NE556 dual timer in astable operation in the range from 200 Hz to 20 kHz. The CD4020B ripple counter divides this frequency by 2^{14} to produce flash trigger repetition rates that can be varied from about 60 flashes/min to less than 1 flash/min. In practice, it was not possible to reliably flash the unit faster than about 40 flashes/min, and although repetition rates as low as 6 flashes/min were used in the testing, rates below 10 flashes/min were too slow to be useful for the type of remote acquisition considered here.

In ordinary operation, the flash unit uses a phototransistor sensor with neutral density filters to trigger a quench circuit when the integral of the light reflected to the unit reaches a preset level.[4] In the modified flash, the phototransistor is replaced by an optoisolator switch, and the other half of the NE556 is used in monostable operation to close this switch after a delay time ranging from 0.05 to 6.0 msec, which is controlled by R5 and C4. The energy of the flash is determined by the length of the pulse, although the relationship is definitely nonlinear. A side benefit derived from controlling the output of the flash with the quenching circuit is that the flash is extinguished without completely discharging the main storage capacitor. This allows a more efficient trade-off between flash energy and repetition rate, given the finite capability of the built-in dc inverter circuit to recharge the main storage capacitor and the limited total electrical energy available on the satellite.

The characteristic shape of the visible light pulse from the flash unit is shown as the envelope of the superposition of pulses in Fig. 3. The pulse traces were recorded with a 1P28 photomultiplier tube and a digital oscilloscope. The initial 50-μsec spike at the beginning of the pulse is typical for the output of a xenon flash tube in the green-yellow

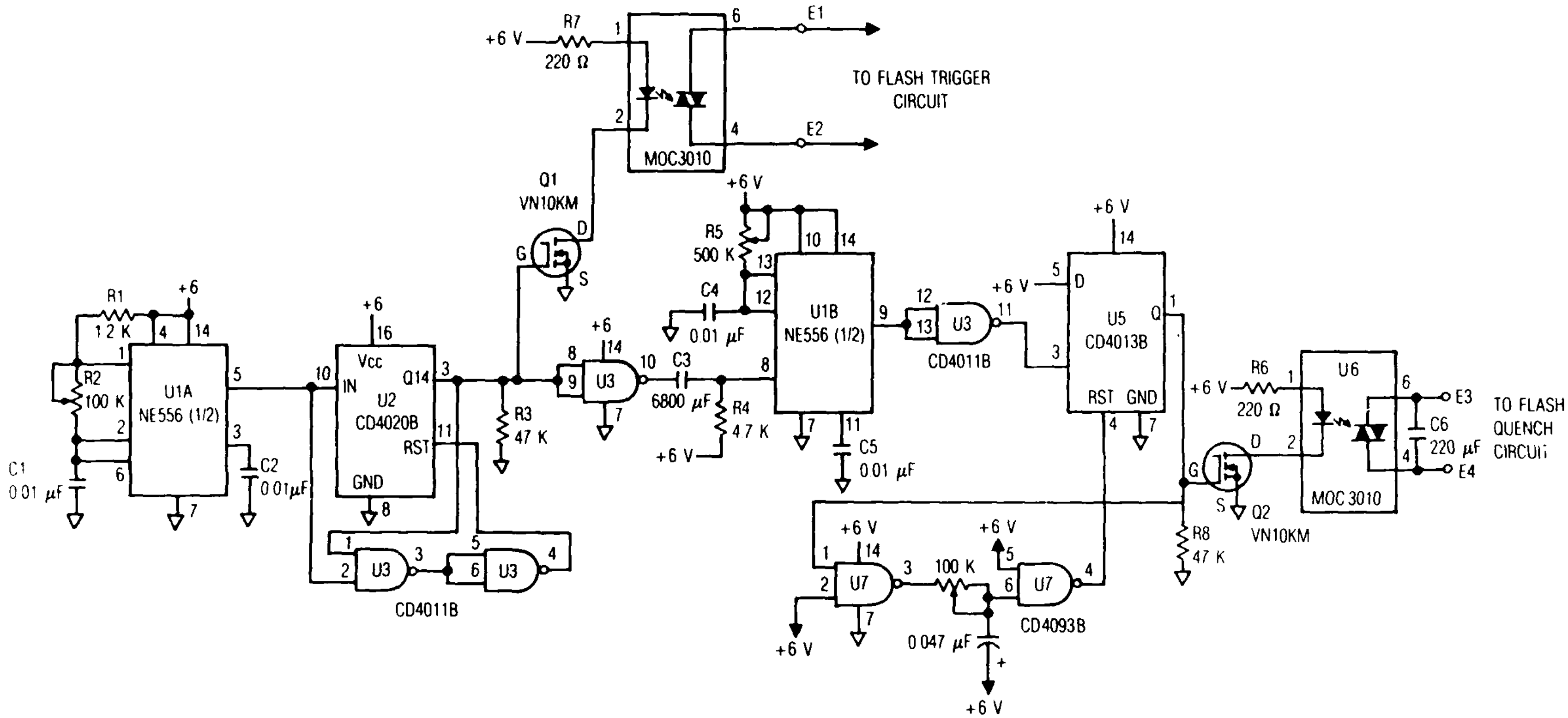

Fig. 2. Timing and control circuitry for the prototype CRO beacon. The flash duration is controlled by the RC time constant set by R5 and C4.

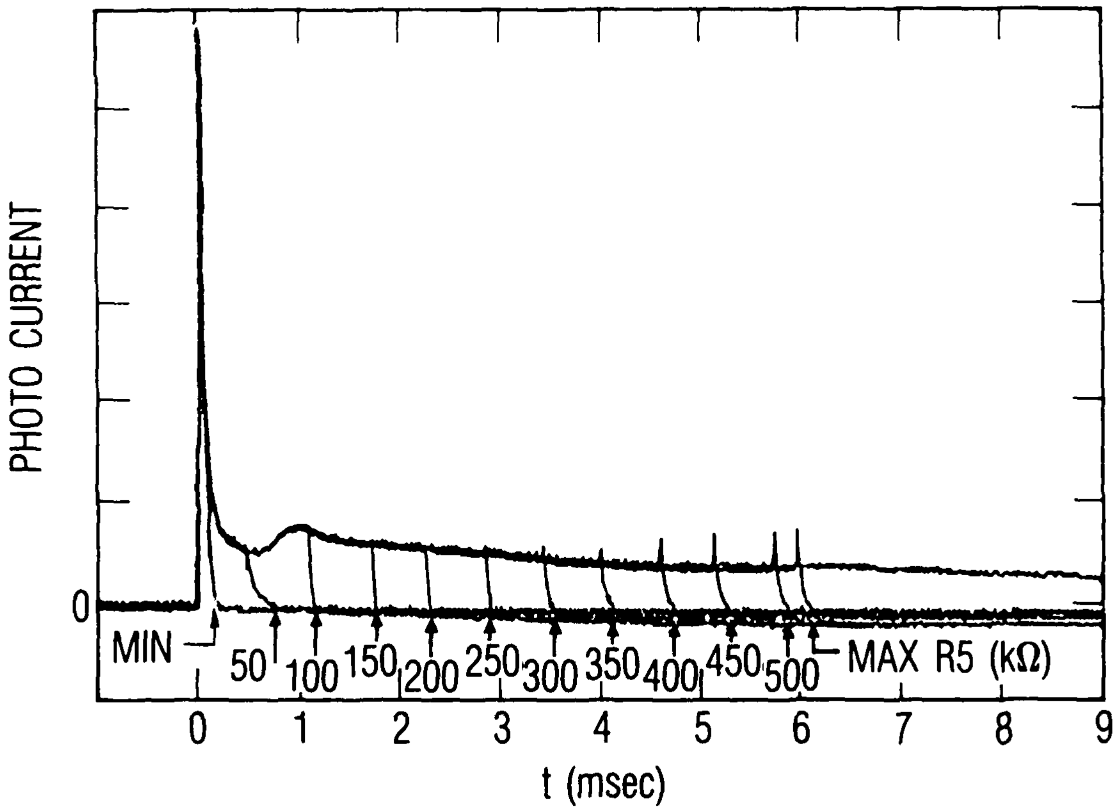

Fig. 3. Oscilloscope traces of the response of a photomultiplier tube to the light from the CRO beacon prototype. The different pulse shapes are annotated with the resistance of R5 in kilohms.

portion of the spectrum. The superposition of truncated pulses is annotated with the resistance value selected with R5 that produced the pulse. The value of R5 was used to designate the flash energy for the purposes of the camera tests.

The standard flash unit has a Fresnel lens to provide some focusing in the plane containing the cylindrical axis of the flashtube and to filter the light slightly to more closely match the spectral characteristics of sunlight. We found that we could obtain about a 20% increase in total light output with the lens removed, as measured with the phototube and with a totally absorbing laser power meter looking straight into the flash. The detectors were placed far enough from the flash to infer that this increase occurs even though the light is spread over a wider pattern. Measurements with an InAs detector and IR filter combinations revealed that the lens attenuated the light from the flash by a factor of 50 beyond 1 μm. This attenuation can be quite important as several TV camera tubes and CCD sensors still have significant response near 1 μm, and this additional near-infrared response might increase the useful range of the flash (without the lens) as a beacon.

The laser power meter and a photographic flash meter were used to obtain approximate radiometric and photometric calibrations of the flash output with respect to the value of R5. These measurements are summarized in Table 1 for the flash with and without the lens. The largest variances were obtained for the laser power meter measurements on the flash without the lens, but even so, the maximum flash-to-flash variability was 5%. This includes the effects of blowing on the flash with a fan to vary the cooling of the tube. The maximum light output for the flash with the lens in place can be compared with the manufacturer's specification of the acceptable output range of 1280 to 2570 cd-sec (candela-sec; actually 138-277 lux-sec at a distance of 10 ft). Note that the photometric brightness (the brightness in the wavelength range of the eye's response from 0.38 to 0.77 μm) of the flash decreases when the lens is removed, but that the overall radiant energy increases. Without the lens, the visible light is spread over a larger range of angles, but more of the emission spectrum is transmitted.

It should be noted that neither the photometric or radiometric calibration measurements can be simply related to the response of the L^3TV cameras that we tested. The cameras are sensitive over a much broader spectrum than the photopic eye response and, as such, can detect sources with very little photometric brightness, which is defined to be brightness only in the visible part of the spectrum. On the other hand, the cameras certainly cannot respond to as much of the emission spectrum of the flash as the laser power meter does. Furthermore, even if we assume a typical xenon flashtube emission spectrum for the beacon (without the color correcting lens) and convolve it with the typical photocathode response for one of the cameras, we still could not reliably predict the response of the camera based upon calculated values derived from the measurements presented in Table 1. This is because there are uncertainties associated with the spectral transmission of the optics used with the cameras and with the contributions from thermal emission by the flash tube itself. However, the calibration measurements probably do provide useful data for comparisons of the responses of the tested cameras to different flash units or configurations of the same basic type.

Removal of the lens had a decided advantage in this application because the cameras considered here are sensitive beyond 1 μm. The increase in apparent brightness obtained by removing the lens was verified in the first field test series, so we used only flash units with the lens removed for the remainder of the testing. It is possible that removal of the lens may have contributed to some of the flash-to-flash variability that was observed with the L^3TV cameras, but in view of the lab tests cited above, we find this very unlikely. The radiometric and photometric measurements with the lens removed do not show as consistent a trend with increasing pulse duration as those with the lens in place. Preliminary measurements indicate that there are differences in the temporal characteristics of the light pulse in the yellow to green vs the red to near-IR (i.e., beyond 600 nm) portions of the spectrum, which we presume are due to the contributions from the heating and cooling of the discharge tube.

Additional lab tests with a GaAs phototube and bandpass filters are under way to characterize the near-IR behavior of the flash and the sensitivity of the emission in this wavelength region to changes in the ambient environment.

IV. FIELD TESTS

Two different kinds of L^3TV camera setups were used to test the utility of the Vivitar model 283 as an optical beacon: a Cohu camera flown by NASA on the Learjet Observatory (LJO) and Kuiper Airborne Observatory (KAO) that has an intensified silicon intensified tube (ISIT) and a pair of Xybion ISS cameras that use intensified charge injection devices (ICID). The LJO was one of several platforms considered for use in the CRO experiment, and its ISIT camera is similar to those used on other aircraft and at some ground-based optical sites. The two ICID cameras tested were modified by the Air Force Geophysics Laboratory (AFGL) for use in space on the Shuttle Pallet System (SPAS) that carries instruments for the IBSS mission. These cameras have each been fitted with a unique 1.4-in.-diam lens system giving one camera a narrow ($2.4° \times 3.2°$) and the other a wide ($11° \times 14.4°$) field of view (FOV). During the IBSS mission, either may be used to acquire the optical beacon on the CRO satellite.

The ISIT has a demonstrated high sensitivity, being routinely used with a 3.5-in.-diam lens to acquire stars of magnitude 11 or fainter (13 being the limit observed with a new tube and fiber optic bundle between the lens and camera). However, for a flashing source, if the flash occurs right after the scan has passed by the spot where the flash signal will appear, the signal can decay a significant amount before the scan returns to that spot. The ICID device is less susceptible to this problem, as it continuously collects photoelectrons arriving at each "pixel" detector until the total charge for the detector is read out. The ICID has had less history in astronomical applications, and was therefore considered more of a risk to observe the beacon. The tests addressed this concern by producing observations of the flash brightness that could be compared against stars of known magnitude with both types of cameras.

A. TEST SERIES 1

On the nights of 8-9 and 9-10 March 1988, a prototype of the flash unit was taken to a hairpin turn about 500 ft below Lick Observatory on Mount Hamilton, California, that could be precisely located on a topological map. The NASA Ames LearJet Observatory guidescope system, which uses a 3.5-in.-diam Angenieux zoom lens as a light collector, was taken to a straight stretch of Quimby road just below the ridge to the southwest. The line-of-sight distance was 4.34 miles, and USGS topography maps were used to pinpoint both locations to a few yards. The objectives of this test were: a) to evaluate the Vivitar flash unit for use on the CRO satellite as a beacon to aid Shuttle astronauts in acquiring the CRO satellite; b) to evaluate the usefulness of the flash as a beacon for airborne measurements at 500 to 600 miles; and c) to obtain video tape of both the flash and of stars with the whole system to use in the preparation of a "training tape" for use by the NASA mission specialists or other sensor operations personnel. Subject to the limitation that the ISIT camera does not respond to the flash exactly like the ICID cameras currently selected for use on the IBSS mission, all of these objectives were met.

The first night, a series of tests with the automatically controlled flash was conducted at various power levels and repetition rates and with neutral density (ND) filters of 0.9, 2.0, and 4.2 (to simulate 12, 43, and 550 miles, respectively). This unit had the color compensating lens installed. The air was very murky, making the use of a 10-mile baseline more unreliable than the use of more ND filters. The sites chosen had the advantages of very dark backgrounds, observatory lights nearby for quick acquisition of the flash site, and a totally unobstructed line of sight over which we could easily use hand-held walkie talkies for clear, quick communication. In addition to the ND filter measurements, tests of the response of the camera to the flash were made with the unit oriented at various angles with respect to the normal head-on aspect.

The ND filters were placed in front of the flash unit in order to compare the apparent brightness of the attenuated flash with stars of known magnitude for the same gain and focal length settings of the camera. Two types of ND filters (glass and Wratten gels) were used with comparable results, so no problems with regard to spectral variation in the attenuation of the ND filters or saturation effects in these filters were expected. After the nighttime experiments, follow-up tests of the ND filters were done in the Aerospace labs, and saturation effects at the levels used for the nighttime tests were negligible. There was a variation in spectral attenuation, but not at a level sufficient to change the conclusions of the test.

The second night, the flash with the automatic triggering circuit failed partway through the tests, so a backup unit that was manually triggered was used for the remainder of the measurements of apparent brightness and angular distribution of the flash unit with the lens removed. The failure of the primary unit was isolated in the trigger circuit of the flash, possibly due to a failure of the tube's trigger electrode. Because of the old age of this unit, this was viewed as normal attrition, but does point out the value of lifetime tests in comparison to the experiment duration. The light outputs from both of these units had been compared with the test setup in the lab using the 1P28 photomultiplier tube and were found to agree within 5% with the lenses in place.

B. SUMMARY OF OBSERVATIONS DURING TEST SERIES 1

Many factors will affect the success of the use of the Vivitar flash as a beacon, and we quickly discovered those peculiar to the LJO camera. In general, ISIT cameras can be run at varying voltage levels (or gain levels) which have dramatically different sensitivities. The LJO system had an auto gain setting (maximum gain on a dark scene) of 6.94 in some arbitrary units related to the value of the high voltage used inside the tube. In addition to the tests done at the auto gain setting, we conducted several tests on both stars and the beacon at lower gain values which were set by hand. In one case, at a gain setting of 4.6, we could only see stars of about the third magnitude, while at a gain of 6.94 we could see down to about the seventh magnitude, or about 40 times fainter. Clearly, the test results presented here demonstrate that a given camera must be set up to be able to "see" stars of a particular magnitude or fainter in order to ensure the successful use of this type of beacon in a particular experiment scenario. If the camera is panning over a scene, the sensitivity will be decreased by a factor of about 5 (2 units of magnitude) for typical slow manual scan rates, and more for faster scans. This margin must be included in the sensitivity requirements for the camera if it is to be used in a scanning mode.

The video scan rate of the TV is 30 frames/sec, and the flash duration is only a few milliseconds. If the flash occurs at random times with respect to the start of the raster scan, it is possible that there may be a delay of as much as 33 msec before the appropriate pixel detectors are interrogated, i.e. "between" frames. If the flash appears bright enough (as it did for our 6.94 camera gain setting, with a flash power setting of 50 and a ND 2.0 filter corresponding to a range of 72 km), bloom and saturation, combined with the persistence of the ISIT phosphor, result in detecting all the flashes anyway, although they did not appear equally bright. With a ND 4.2 filter (aircraft distance, roughly 910 km or 550 miles) and at the power setting of 50, we could still see the flashes, but the scintillations in the camera flicker on and off just like the beacon does. Without knowing where in the field to look, we would not have identified the flash under these conditions. Turning up the power to 150 resulted in an easily discerned flash image even with the ND 4.2 filters. Thus, an aircraft (which could have a more sensitive system utilizing, for example, a 10-in.-diam collector) should be able to acquire the beacon at a range of the order of 500-600 miles.

It was our impression that the (backup) flash unit without the lens appeared appreciably brighter than the unit used the first night. Although the air was much clearer the second night than the first, we were conducting our test over a relatively short distance, so we believe the removal of the lens is the source of the extra brightness. Removing the lens also results in more off-axis flux, further enhancing the chances of detection if the satellite axis is not aimed directly at the observer.

We also found that, with the ISIT camera, repetition rates of 1 flash every 3 or 6 sec were too slow; the observer needed to see more flashes, even if they were a bit fainter, to convince himself that they were real. A rate of 40 flashes/min seemed to be a good compromise between rate and power. For the Shuttle scenario, power level 50 was more than adequate for the sensitivity of the LJO ISIT system. Power level 150 was enough to meet the aircraft requirements as well, although power level of 50 might be sufficient if an ISIT camera were used with better sensitivity than the LJO system used here, and/or the camera had fewer scintillations (random, short-lived bright specks in the field when the camera is operated at high gain).

The measurements of the camera response with respect to the line-of-sight angle to the flash showed that, within a range of ± 45 deg in azimuth (the angle measured with respect to the center of the flash pattern in the plane containing the cylindrically symmetric axis of the flashtube) and ± 30 deg in elevation, the flash did not appreciably degrade in brightness. We are confident that if the line of sight of an observer to the flash is in the range of these angles, there is a good chance of detecting the beacon with a camera similar to one of the types used for these tests.

Copies of the two VHS recordings of the LJO camera output with our verbal documentation made in real-time with a microphone plugged into the VCR are available from The Aerospace Corporation. Video recordings of the setups used are also available.

C. TEST SERIES 2

The second series of tests used the Xybion ICID cameras as modified by AFGL. Due to the nature of the ICID, there is no dead time "between frames" as it were, so we expected that if these cameras were sensitive enough to detect the flash, there should be an improvement in the uniformity of the appearance of individual flashes. This should be a significant advantage over a system using an ISIT to find the flashing beacon. These cameras are also lighter and more compact than the ISITs we have operated in the past, and are believed to be more rugged.

For the tests of the ICID with the prototype CRO beacon, the two cameras were transported to Kitt Peak National Observatory outside Tucson, Arizona, by AFGL personnel. NASA observers recorded the tests on Super VHS video tape. The beacon was set up on Mt. Lemmon, 92 km away, in a fashion similar to that described for the first field test. This afforded the nominal baseline for Shuttle operations without the need for neutral density filters. There was a distinct haze between the two mountain tops, and lights on Mt. Lemmon were seen to "twinkle" at a significant level, although the view toward the zenith was clear and reported to be of photometric quality by astronomers on the nearby telescope.

D. SUMMARY OF OBSERVATIONS DURING TEST SERIES 2

A series of observations was made with both Xybion cameras (wide- and narrow-field of view) for various power levels and flash repetition rates, much as was done before with the ISIT camera. The variation in intensity of the individual flashes was much greater than expected with these cameras. (Photomultiplier output recordings made of many flashes in the lab were repeatable to about 5% vs more than a factor of 2 variation observed at the test site.) As noted above, nearby cw sources also showed considerable variation due to atmospheric effects, as might be expected for a line of sight passing above a major city like Tucson. These observations are consistent with the correlation time for atmospheric transmission effects of 1-3 msec reported by Menyuk and Killinger[5] and references therein. On orbit this will not be a problem, and the flash may appear generally brighter as well, thus increasing the range at which the flash can be detected without increasing the power requirements.

In Fig. 4a, the wide field-of-view image without the flash has been reproduced from the video tape made during the test. In Fig. 4b, the same scene with the flash is shown in a photograph of a single frame in freeze-frame mode. Even though this image was recorded when the flash was at a power setting of 150, the image is very bright, if not saturated. Comparing the tape images of the flash with those of the Pleiades suggests the flash is brighter than a third magnitude star, and maybe as bright as magnitude 0 to 1.

In Fig. 5, the narrow field-of-view image of another flash at the same power setting is shown. The additional scintillations (speckles) seen in this image are due to the camera operating at higher gain under the lower illumination level associated with a narrower field of view. Note the extreme saturation and yet modest bloom of the flash image. None of the surrounding lights were within this narrow FOV, which explains the absence of any other images. A faint shadow of a nearby hill can be seen on the original video tape.

In Fig. 6, a narrow field-of-view image of the constellation of the Pleiades can be seen. The magnitude limit is approximately nine, corresponding to a flux of about 8.0×10^{-17} W/cm^2 over a nominal 4800-6800 Å visual bandpass filter. (Note that the camera is actually responding to a wider bandpass in these tests, but this flux is referred to a standard V filter for reference purposes - see Allen,[6] for more complete information on calibration.) This is a more than adequate test of sufficient camera sensitivity to be able to detect the flash in the operational situation. The increased sensitivity does provide the added benefit of detecting enough background stars to use them for pointing and tracking information.

In summary, test fields of the Pleiades, Orion, Cassieopeia, and two planets (Jupiter and Mars) were obtained with the ICID. The camera, using a 1.4 in-diam collector, was able to see to ninth magnitude, two magnitudes (a factor of 5) fainter than the requirement derived during our first tests for being able to detect the beacon on-orbit for our particular application. Again, the new observers and camera operator verified our choice of a relatively fast flash rate ($\geq$ 0.5 Hz) at a somewhat reduced energy per flash over a slower rate with more energy per flash for the optimum visibility/detectability. The flash was again visible with both cameras at all power settings of 50 or greater, but an R5 value in the 100-150 kΩ range is preferred if the corresponding power drain of the CRO satellite batteries can be tolerated. The resulting increased brightness would enhance the usefulness of the beacon at larger ranges, such as those encountered in an airplane-based experiment, but the power drain rate allowed will depend on the total amount of time the beacon is required for the IBSS/CRO fine pointing maneuvers combined with the total power available on the satellite.

Fig. 4a. The image recorded on video tape from the WFOV camera with no flash illumination.

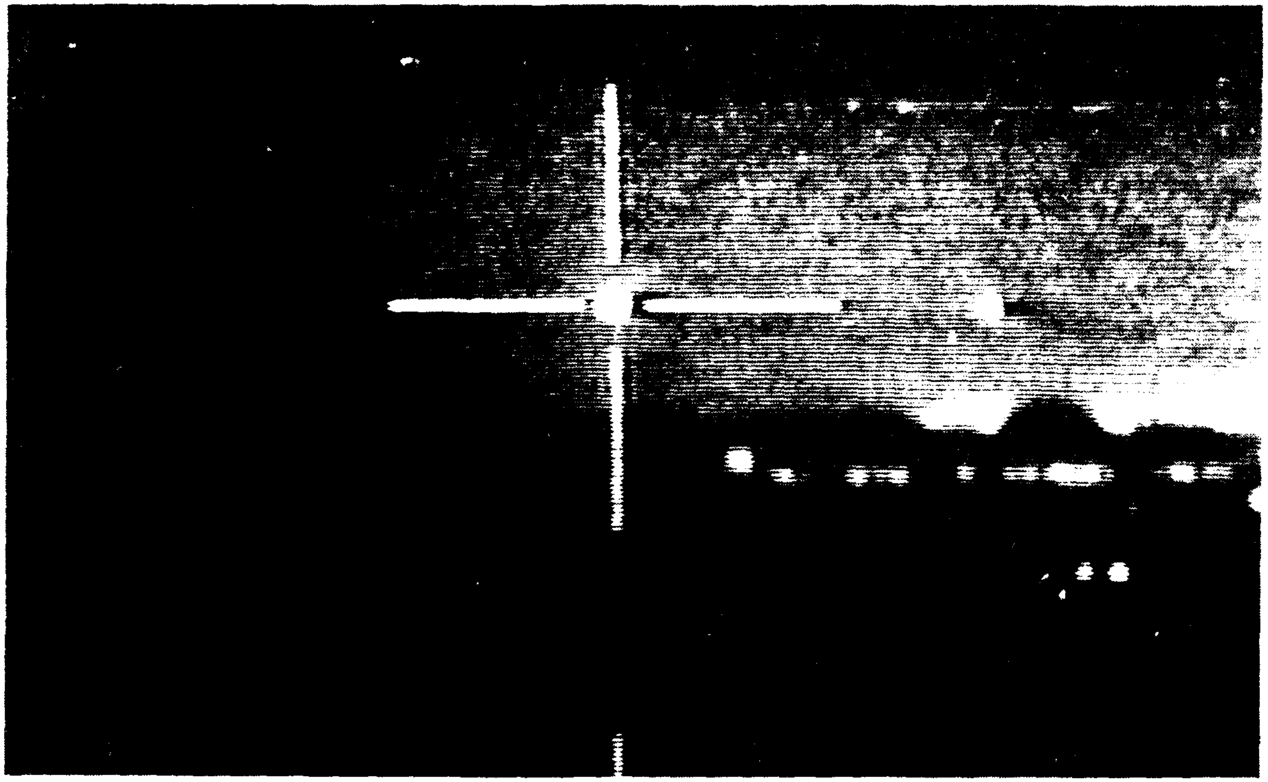

Fig. 4b. Photo of a single frame from the video from the WFOV camera with the flash in the cross hair. As the flash duration is about 2 msec, the flash was only observed in 1 video frame per flash.

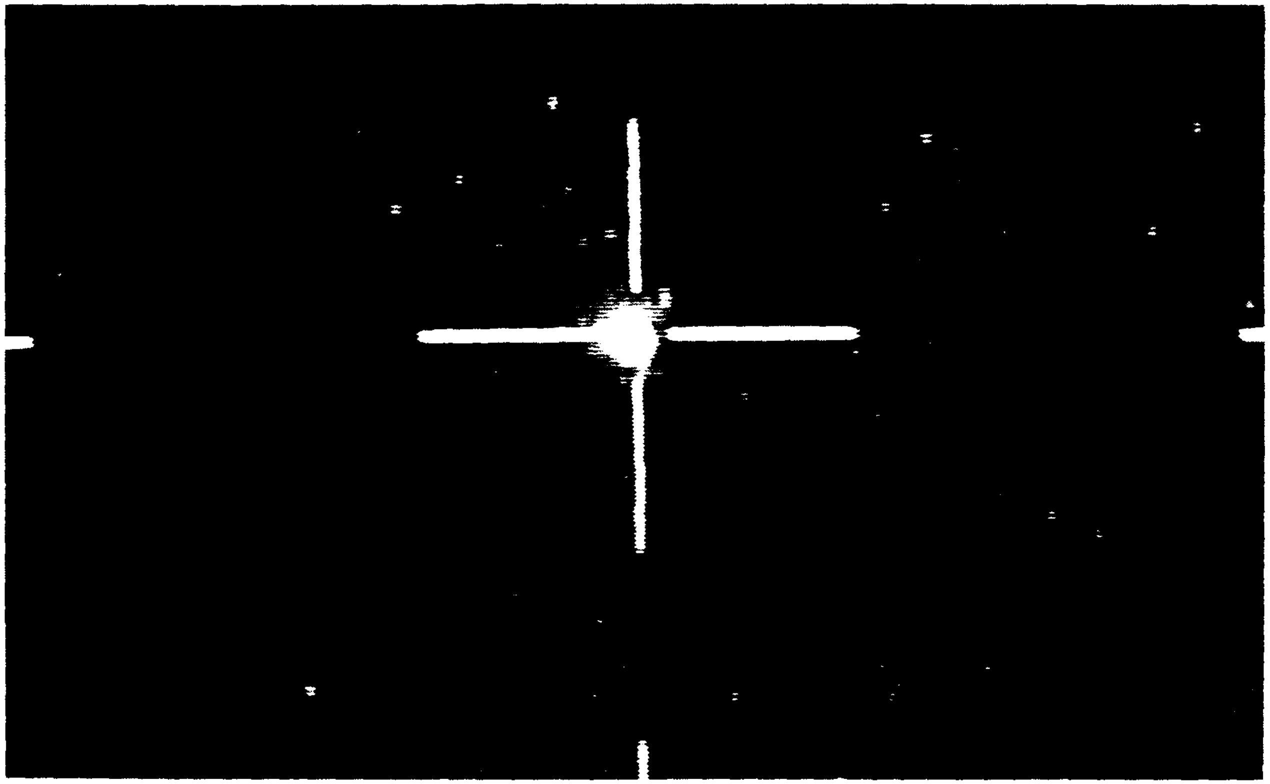

Fig. 5. As in 4b, but for the NFOV camera. The smaller field precluded any of the surrounding lights from being viewed while the flash was centered in the field of view. The "speckles," or scintillations in the photo are due to the camera itself, and are common under high gain, low-light-level operation. Their position is random from frame to frame, and provides a noise floor above which the flash has to be perceived.

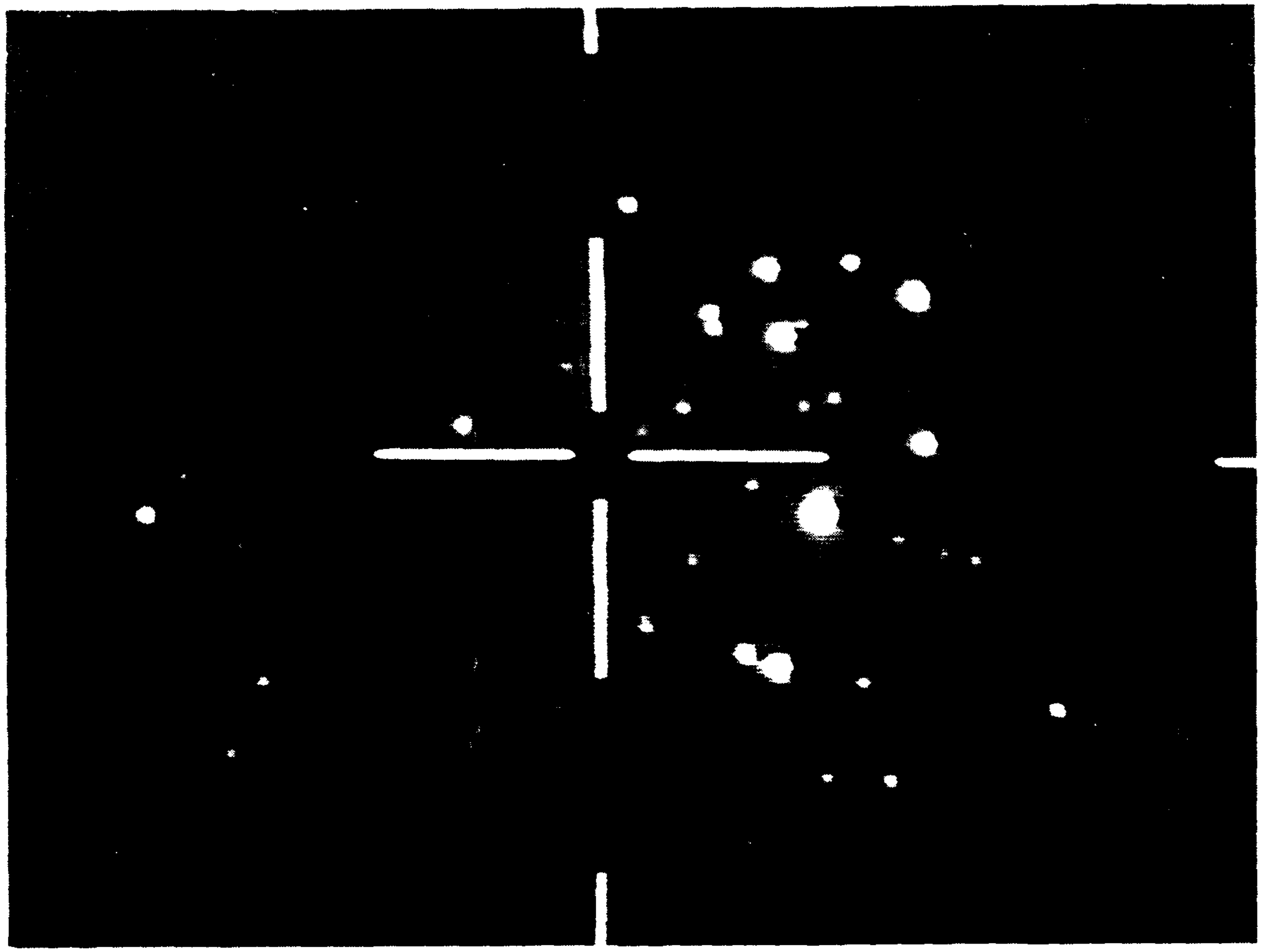

Fig. 6. The NFOV image of the Pleiades (Seven Sisters) star cluster. Although some of the fainter detail is lost in this reproduction of a photo of a monitor screen, stars as faint as visual magnitude nine can be seen during playback. The flash appears to be brighter than a third magnitude star for the 92-km range tested here.

V. CONCLUSIONS AND RECOMMENDATIONS

A relatively inexpensive, low power consumption, high reliability modified flash has been developed and successfully tested for use as a beacon in remote acquisition situations. This unit is well-suited for use on low Earth orbit satellites or between two airborne platforms, for example. Trade-offs of visibility and power consumption make this a versatile alternative to high-powered airplane strobes or searchlights. Tests with ISIT and ICID L^3TV systems have shown more variability than expected in displayed flash intensity; this is tentatively attributed to millisecond time-scale fluctuations in atmospheric transmission over the long horizontal lines of sight used for these tests. The ICID camera has some advantage over the ISIT camera because the short duration of the light pulse produced by the flash can occur "between frames" for the ISIT, while the ICID integrates continuously. Either type of camera will satisfy the requirement of finding the beacon for the IBSS/SPAS scenario as long as it is sensitive enough to see seventh magnitude stars. This sensitivity can be achieved by either the use of a low-noise camera at high gain, or a moderate sensitivity camera with a larger telescope.

The performance of our prototype optical beacon was superior for this application without the plastic lens on the flash unit. Removing the lens resulted in a brighter signal and a larger range of angles over which the beacon could be observed with either type of camera tested. This will probably be the case for any xenon flashtube camera strobe that might be modified for use as an optical beacon. With the Vivitar 283 camera flash, a repetition rate of about 0.5 Hz and a pulse duration between 1.0 and 2.0 msec appears to be the optimum trade-off between visibility and power consumption. Video tapes of the setups and tests are available at The Aerospace Corporation.

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